

Investigation of a New High-speed Tabletop Interaction System

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Abstract

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In this project, we built up a high speed interactive tabletop infrared tracking system, based on the existing Qualitrack system [1] [2]. This system can detect the position, orientation and state of each infrared emitting input device in real time. The output of Qualitrack is implemented according to standard TUIO protocol. Any applications software understanding TUIO protocol can be docked with Qualitrack smoothly.

Based on the documents of the existing system, we built up the whole system architecture, the infrared pen, the infrared air hockey paddle and corresponding application software for Qualitrack system. As an in-house contribution, we created two new input devices, namely the magnifier and the color filter, to enrich the input device types of Qualitrack system.

In order to explore the influence of tracking update rate on the user interaction performance, three user experimental tasks were designed and user studies were conducted. The corresponding user study application software was also developed.

Key words: tabletop system, infrared tracking, TUIO protocol, user study

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1. Introduction

In a European collaboration between t2i Lab Chalmers University of Technology (CTH) Sweden and ICVR research group Swiss Federal institute of Technology (ETH) Zurich, a new high speed interactive tabletop infrared tracking system, called Qualitrack, was developed. A smaller part of this system (approximately 20%) was developed at CTH. ^[3]

For a set of input devices positioned at or directly above the table, the system is capable of simultaneously tracking each device's position, state, and orientation in real time. The system-tracking rate of 250Hz provides smooth and reliable device registration.

Every input device contains an integrated infrared receiver and a signal processor. They are synchronized by a hardware called SyncUnit^[3] and emit synchronized infrared light pulses. According to a particular bit code algorithm, each device uses a unique infrared light pulse sequence enabling device identification.

The output of Qualitrack system is implemented under the standard TUIO protocol so that any applications software understanding TUIO protocol can be docked with it smoothly.

Figure 1.1 is the structure diagram of Qualitrack system. And Figure 1.2 is the photo of Qualitrack system.

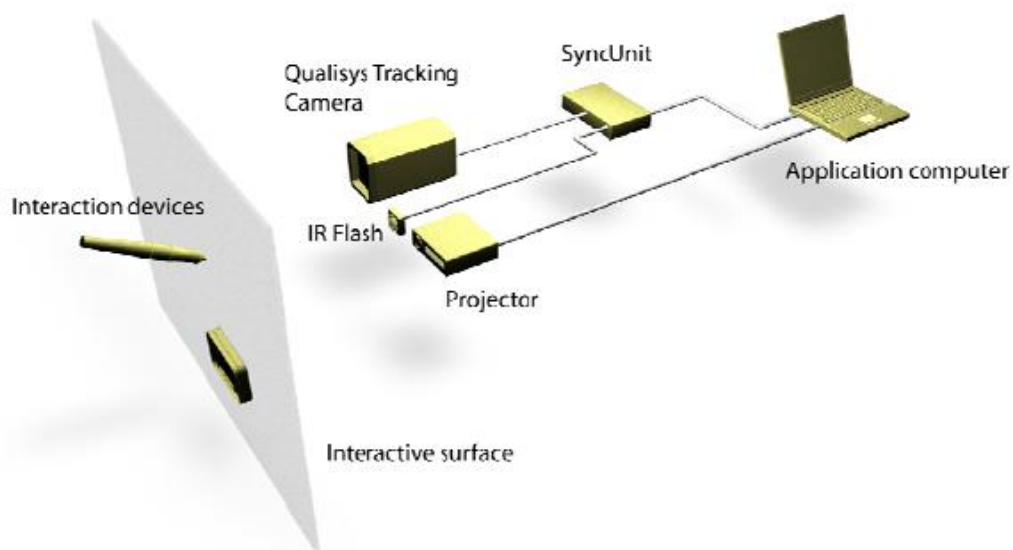


Figure 1.1 structure diagram of Qualitrack system ^[1]



Figure 1.2 Qualitrack system

1.1 Related Works

Only several academic institutes are engaging in developing visual based multi input devices tabletop system in the world until now.

Device identification is one of the core research questions for multi device tabletop system. There are several device identification methods in different systems. For instance, DigitalDesk^[4] recognizes the input devices by shape. InfoTable^[5] identifies devices by marker. And pHotOluck^[6] distinguish input devices by color.

Regrettably, there isn't any system can provide reliable device identification with high speed tracking update rate. Most of the visual based tabletop system only can works at a low tracking refresh rate. For example, InfrActable^[2] system can identify seven input devices at the same time but its final update rate is only 20Hz, which is too low. Simulated Table Top Tennis^[7] is a system can work at 60Hz.

Compare with the other existing system, Qualitrack can support five different input devices working in parallel with tracking update rate up to 250Hz, which is rather higher than other similar systems.

1.1 Research Aims and Questions

This project was driven by three goals: The first one is to set up the platform of Qualitrack system, implement all the necessary devices and develop the corresponding application software. The second goal is to develop a new input device for Qualitrack system. The last goal is to design and carry out a user study experiment so as to analyze the influence of the tracking update rate on

the user interaction performance with Qualitrack system.

Around these goals, the work package of this project was divided into three sections and each section can be refined into two or three subsections.

1. Set up the Qualitrack system.
 - n Implement hardware and software
 - n Integrate hardware and software
2. Develop new input device
 - n Design and implement hardware and software
 - n Merge the new device into Qualitrack system.
3. Carry out user study experiment.
 - n Design user study experiment
 - n Develop user study application software
 - n Carry out user study and analyze data.

1.2 Research Process

This project was divided into 4 sessions.

Session 1 Literary study

During this session, we got familiar with Qualitrack system by reading old documents. And due to none of us study exactly human computer interaction (HCI), one of us studies Computer Science and the other's major is Mechantronics, we had to read some materials and relative papers in this research field so as to get a clear sketch of HCI and distinguish the similarities and differences between HCI system development and usual computer system development.

Session 2 Project design

In this session, we delimited the work package which is mentioned in Chapter 1.1 and design the user study experiment. Brainstorming offered us quite a lot inspiration in our group meeting. And we decided to use lab experiment method in our user study due to its controllability feature and our technology education background.

Session 3 System development

Due to this system was put on the shelf for about two years, all the hardware devices had lost or been damaged, we have to rebuild all the hardware devices. And we must develop almost all the application software by ourselves under the situation that lack of relevant specification document. We tried our best to reuse existing software components and hardware design so as to keep the original

system features as much as possible. Object oriented thinking and software reuses thinking reduced our time cost efficiently and enhanced the code quality effectively. The two project group members worked separately in a long period (6 weeks). One worked in Switzerland with all the hardware and the other focused on software development in Sweden. To communicate efficiently and get the user experience response in time, we chose prototyping as our software development method.

Session 4 User Study experiment

This is the last session of this project. Ten volunteer participants are involved in a three tasks user study experiment.

During the entire four sessions, we used some engineering and experimental methodology. These details will be explained in Chapter 3.

1.3 Delimitations

The user study was only carried out within a small group size for the reason of limited time. This project will develop and set up Qualitrack system platform and develop the entire user study hardware and software environment so that other people can do a further user study based on our work in the future.

1.4 Thesis Outline

This section outlines the thesis structure. A brief description of each chapter and its contents is mentioned below.

Chapter 1 (Introduction) introduces the general context in which the project is carried out and describes Qualitrack system in general. The research questions of this project are defined and delimitations are described.

Chapter 2 (Background) renders the background knowledge of the project. Necessary relative concepts are defined.

Chapter 3 (Method) covers the engineering and experimental methodologies adopted to carry out this project.

Chapter 4 (Qualitrack System) provides the technical details of the Qualitrack system; elaborates the design and implementation of the new magnifier and color filter devices; Illustrates the design and implementation of the user study application software.

Chapter 5 (User Study Experiment) describes the user study experimental

design and analysis of the experimental data.

Chapter 6 (Discussion) discusses the problems in this project and explains the result of the user study experiment

Chapter 7 (Conclusion) concludes the observations and results.

Chapter 8 (Future work) shows some topics for future research.

2. Background

2.1 Visual Based Tabletop System

A tabletop system supports a digital horizon surface which a group of people can work around in collaboration. Table top user interfaces can preserve many of the familiar and useful properties a physical tabletop affords and allow the natural interaction. ^[8] Figure 2.1.1 shows an example of tabletop system.



Figure 2.1.1 a collaborate working around a digital table.

A typical visual based tabletop system usually contains three parts.

- I Input unit, which generates the input data, such as infrared pen. In some multi tangible implementation like NUI Group's Community Earth even human finger tip can be used as input device.
- I Tracking unit, which is the core of a visual based system. Usually, a digital camera is used to capture the physical input signal such as infrared light. The input data is processed by a host computer. And the output data is forwarded to the display unit.
- I Display unit, which show the static background images and dynamic output images on the table surface, for instance a projector.

Tabletop system involves the thinking of Augmented Reality (AR). For quite a long time, people paid too much attention and effort to Virtual Reality (VR). We tried to move everything in our real world into computer screen. Without going into the social the physiology problems generated by VR, at least nowadays computer technology is still not advanced enough to make people feel natural in

most of the VR environment. For example, drawing with a mouse is definitely not a good experience. However, AR supplements the reality, rather than completely replacing it.^[9] The idea of AR is merge the virtual environment and real world environment together organically. Let's still take the above simple example. People will feel much natural if he or she drawing on a digital table with an infrared pen, instead of using a mouse drawing on a mouse pad.

2.2 TUIO

TUIO Protocol is specifically designed for the needs of tabletop tangible user interfaces: encoding and transmitting the attributes of tangible artifacts that are found on a table surface.^[10] Since TUIO is based on Open Sound Control (OSC), it can be seen as a slandered implementation of OSC.

There are three main kinds of messages in TUIO protocol. SET message, ALIVE message and FSEQ message. Set message describes the status of an object, such as position and orientation. Alive message is used to identify the objects which are working right now with a specific session ID. FSEQ message is defined as the unique tag to distinguish the frame update. TUIO protocol forwards the encoded data from a TUIO server (such as a visual based tracker) to TUIO client (application which can decode TUIO package).

Except for working as a rule, TUIO also supports a framework which defines this common protocol and APIs. There are more and more third party development libraries and TUIO client implementations in various programming languages support this protocol.

2.3 RXTX

One of the conventional Java serial port communication development libraries is comm2.0.jar, which is published by Sun in 1988. The other one is the open sourced RXTX, which covers all the functionality of Sun's comm2.0 and can support more operation systems.

There are thirteen interfaces and classes in RXTX library. To access the details about these prototypes please check RXTX Javadoc. Here I only introduce the two classes and one interface which are been used in this project.

- I CommPortIdentifier class, which is the central class in RXTX. It controls the access of communication ports.
- I SerialPort class, which defines the functionality of serial communication ports.

I SerialPortEventListener interface, which propagates serial port events.

In a typical serial port communication application, CommPortIdentifier discovers and opens an available communication port in initialization phase. Then, the application can call the methods in class SerialPort to access data through this port.

Usually, there are two ways to monitor the input data stream. One is polling, the other is listening. In polling mode, a polling thread has to be created manually. In this project, listening mode is used with the SerialPortEventListener interface, which supports standard Java event-driving mechanism.

These are tones of corresponding tutorials online, but most of them mislead the reader about how to deploy RXTX. To deploy RXTX, we need to copy RXTXcomm.jar to <jdk_home>\jre\lib\ext\ and Copy rxtxSerial.dll to <jdk_home>\bin\.

3. Methodology

3.1 Brainstorming

Brainstorming is a kind of group creativity collection method created by Alex Faickney Osborn in 1938. The aim of brainstorming is to spur people open their mind so as to generate new ideas. Osborn proposed that groups could double their creative output with brainstorming. ^[11]

In order to get a satisfied result from brainstorming meeting, we followed a set of procedure and obeyed some rules. ^[12]

- I First of all, we determined one clear and concrete topic for every meeting instead of a dozen of general topics.
- I Secondly, all participants was noticed and ensured to clear the topic and asked to do some preparation, such as read relative materials before the meeting.
- I Thirdly, we kept the group size around five people. If the group size is too small, we can't collect enough inspiration. On the contrary, the meet will become hard to control if there are too many participants.
- I Fourthly, we cleared the three kinds of roles and their responsibility in our brainstorming meetings: the moderator, the sectary and the participants. At the beginning of the meeting, the moderator must emphasis the topic and the discipline of the meeting. During the meeting, the moderator made some summary in time and led the meeting to another climax. The sectary's task was to record all participants' the new ideas and write them on the white board so that everybody can see the points clearly. We required every participant must perform active enough.
- I Fifthly, it was definitely forbidden to make any judgment on people's idea during the meeting in case of influencing the participants' positivity. Judgments were left to after the meeting.
- I The last but not the least, our brainstorming meeting was controlled within 30 to 45 minutes every time. If the meeting continues too long, the participants will feel tired and can not concentrate any more.

3.2 Lab Experiment

There are several existing evaluation methodologies which can be used to evaluate a computer system, such as Heuristic evaluation, User testing, Field study, Interviews & Questionnaires and so on.

As one of the most commonly used evaluation approach, laboratory experiment is particularly used to collect quantitative data about a single specific factor, attempting to screen out other influences.^[13] Since tracking update rate is the only independent variable in our user study, our user study exactly conforms to the "single specific factor" condition. It is common in experimental design where factors such as the quality of the user's performance are used as dependent variables, and measured on a quantitative scale.^[14] The idea is applied in our user study faithfully.

Our main goal in this project is to set up the Qualitrack system platform so as to support future project student to do a deeper user study with it. So our user study can be seen as an early stage of the future evaluation. With laboratory experiment method, we can involve available users (students) as our participant to investigate one and only one point of this system within a short time. Then we can leave the more complicated issues to the future project student and the real commercial end users.

Above all lab experiment is the most suitable methodology for user study part in this project.

3.3 Software Reuse and Object Oriented

Software reuse is the process of creating software systems from existing software rather than building software systems from scratch.^[15] This concept is first proposed at the NATO software engineering conference in 1968.

Nowadays, the concept of software reuse is been extended from code reuse to design reuse, analysis reuse, document reuse and so on. The basic idea of software reuse is that form the software by some functionality independent components. Under this idea, all the components must be designed as universal tool for similar work. And Then the procedure of software development will become as simple as playing toy brick. Namely, to develop software, the developers just need to assemble different components. Above all, software reuse is one of the goals in software engineering.

But there are several factors hinder we achieve this goal. First of all, it almost impossible to find a coincided software component, since specific project usually

has special requirements. The second obstructive factor is human factors. Different programmer has different developing habits. Sometimes, it is even harder to modify other people's software to fit for our need than developing a new one by ourselves. Thirdly, some people hold the opinion that reuse code or component is not really creative work. The last but not the least factor is there is few course and textbook mention software reuse in computer science education.

Object Oriented (OO) is the one of the major methodologies in modern software development. It is very hard to give the definition of object oriented, since nowadays OO is not only be limited to Object Oriented Programming(OOP), but also been extended to several different lays, such as Object Oriented Analysis(OOA)and Object Oriented Design(OOD). OO method provides a strong technical support for software reuse. It can prevent software development from meaningless duplication solutions. Thus reduces the financial and human resource cost in software development.

In this project, we tried our best to reuse existing framework and program components so as to reduce the time cost and enhance the code quality. Two popular object oriented programming language, Java and C++ were used in this project. And OpenFrameWorks architecture was applied in the air hockey application program. The writing and drawing task user study program was developed based on slandered TUIO client application.

3.4. Prototyping

Prototyping is a limited representation of a design that allows user to interact with it and to explore its suitability. ^[16] In fact, people use prototyping method unconsciously every day. The most typical example of prototyping is sketching on a piece of paper when one illustrates his or her idea to others.

In software engineering, we usually use computer based prototyping method, so called high-fidelity prototyping, instead of a paper based one. A computer based prototype is an early stage runnable version of a program which shows its most important features. The prototype gives the designer a functional working model of their design so they can work with the design and identify some of its possible pros and cons before it is actually produced. ^[17] Another significant aim of building a prototype is to let the user have an intuitive experience with the program, so that they can support the designer some valuable response. The designer will modify and refine the current prototype acceding to the response from the user and create a new prototype as a result. Create prototype, user experience, refine prototype, the same loop iterates again and again. Finally, there will be a prototype which meets all our requirements. Namely, it is the final product.

In this project due to in quite a long time, one of the project students worked in Switzerland with all the hardware, while the other one developed software in Sweden. From the software developer's point of view, the hardware developer was just the software user. The programs were sent to user as a prototype whenever a functionality of software had been implemented. Then the user tested the software usability with the hardware and gave the software developer response in time.

It is not hard to imagine what will happen if the software developer implements all the software independently without prototyping thinking. When he gets the hardware, he definitely has to spend quite a lot time to modify the software so as to match the hardware. However at that time, due to the complexity of the multifunction software, it will take much more time than just modifying a pure functionality unit.

4. Qualitrack System

4.1 Hardware

4.1.1 SynchUnit

The SynchUnit hardware was developed based on the Olimex SAM7-P256 development board equipped with an Atmel AT91SAM7S256 micro controller. This unit is responsible for the synchronization of the digital camera and all infrared flash input devices. It also takes charge of processing the camera output signals and forwarding the devices statuses data to the host computer. Figure 4.1.1.1 is the Olimex Sam7-p256 development board.

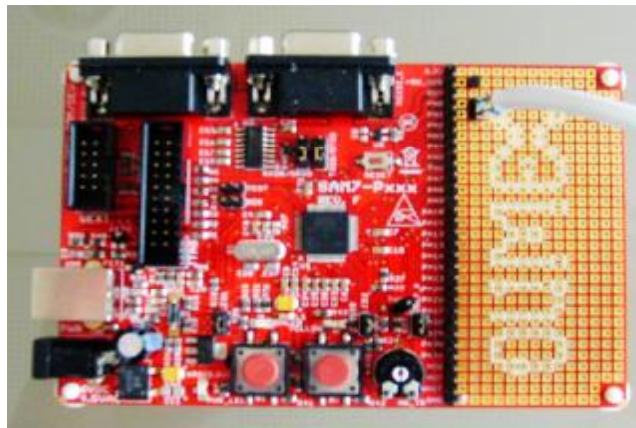


Figure 4.1.1.1 Olimex Sam7-p256 development board

In order to filter out potential noise and make the signals which access to the camera more stable, a RS 232/485 converter was built. This converter transforms the RS 232 signals into differential 2-channel signals used in the RS 485 standard. A three ends RS485 cable was built. One end of this cable was connected to the serial port of the SynchUnit, the other two ends were connected to the service port and data port of the digital camera respectively. This design enables the use of longer cable without decreasing the signal quality. Figure 4.1.1.2 is the photo of the RS 232/485 converter

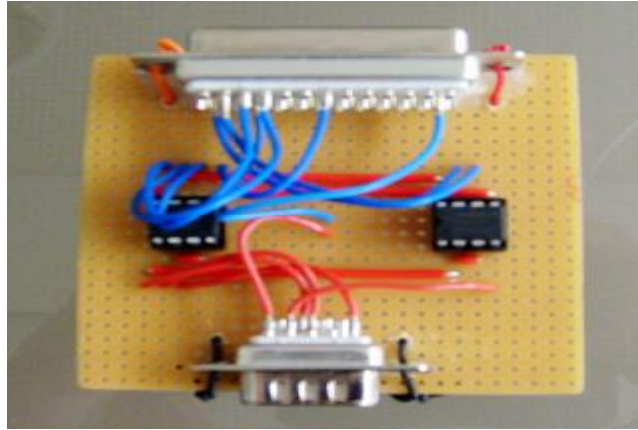


Figure 4.1.1.1 RS 232/485 converter

4.1.2 Input Devices

The devices were built as self powered units consisting of a microcontroller, an IR receiver, a 3.7 Volt battery, a voltage converter, and one or multiple IR LEDs.

When the receiver detects an external infrared light, the micro controller will validate it in order to ensure it respond to the synchronization signal rather than a noise signal.

The amount of LEDs depends on the specific application design of a device. Point device such as the pen are equipped with one single LED, since their position on the tabletop surface is the only valuable information for this system. Line device are equipped with 3 LEDs. For example the air hockey game paddle whose orientation is required in addition to its position. Figure 4.1.2.1 is the photo of the input devices of Qualitrack systems.

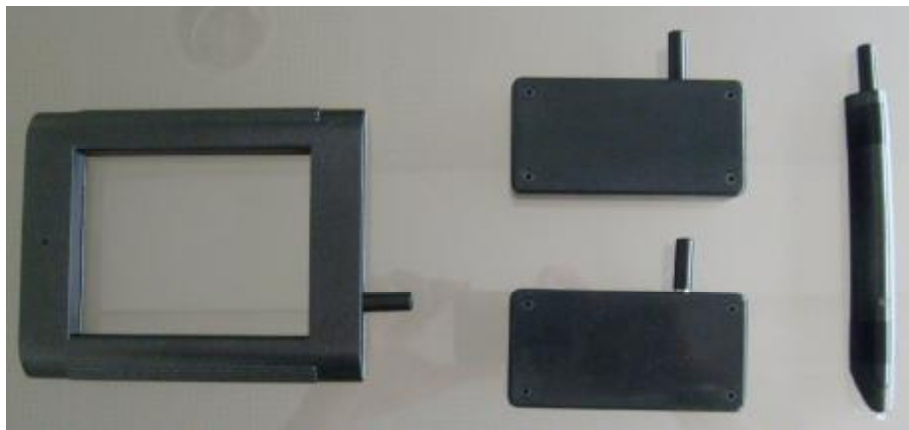


Figure 4.1.1.1 input devices

(from left to right: the magnifier, the air hockey game paddle, the IR pen)

4.2 Software

4.2.1 SynchUnit

SynchUnit is a real time embedded solution developed on Olimax Sam7-p256 development board. It takes the responsibility of synchronizing the whole system and forwarding data from the infrared camera to the host computer. Our project is base on some exciting work. We got the bin file of the SynchUnit. SAM Boot Assistant (SAM-BA) is used to burn this bin file into the flash memory of Olimax Sam7-p256 development board.

Before being able to use SAM-BA, a recovery procedure which consists of copying the SAM-BA Boot Assistant into the first two sections of the on-chip flash must be performed as follows

- I Power down the development board**
- I Close the Jumper TST**
- I Power up the development board**
- I Wait 10s**
- I Power down the development board again**
- I Remove the Jumper TST**
- I Power up the development board**

According to our experience, it is essential to unplug the JTag from the Olimax Sam7-p256 development board when carry out the above recovery procedure.

When the Olimax Sam7-p256 development board is connected to the host computer at the first time, the operating system requires a configuration file to identify and initialize it. The initialization file, "SynchUnitDriver.ini", is modified from a FreeRTOS demo application.

4.2.2 Camtracker

The Camtracker program is the core software of Qualitrack system. It takes charge of starting up the tracking system (both hardware and software), receiving input data from the SynchUnit, identifying the infrared input devices, generating and forwarding TUIO packages. Figure 4.2.2.1 is the structure frame chart of Camtracker program.

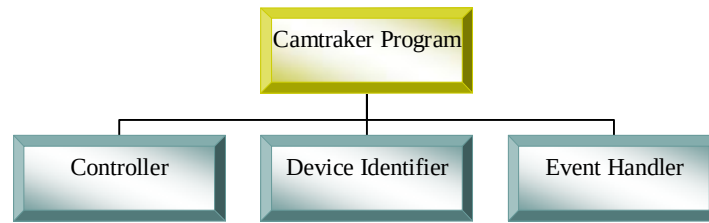


Figure 4.2.2.1 structure frame chart of Camtracker program.

The Camtracker program can be divided into three main modules.

- I **Controller** modular controls the initialization and configuration of the whole system.
- I **Device Identifier** modular identifies the input devices, updates the devices' status and generates corresponding event.
- I **Event Handler** modular handles all kinds of events come form Device Identifier modular.

4.2.2.1 Serial Communication

SynchUnitConnector class configures the IR camera property and the tracking update rate of the whole tracking system in its **Init()** method. After initialization, it creates a thread to receive camera data from the **SynchUnit** and forward these data to **DeviceIdentifier** class. This class is based on **RXTX** to achieve serial communication functionality and implements the **SerialPortEventListener** interface so as to monitor input data stream.

There are two center methods in this class, **Init()** method and **serialEvent()** method.

The **Init()** method takes charges of the initialization issues. Figure 4.2.2.1.1 is the flow diagram of the **init()** method. To Initialize and configure the communication between the **SynchUnit** hardware and the host computer, the **SynchUnitConnector** object set up the serial communication ports and corresponding communication port properties, such as baud rate and parity check bits in **init()** method. And then, it mounts **RXTX** serial event listener to receive input data and starts a thread loop to forward the arriveds data to **DeviceIdentifier** objects. In the end, it triggers the **SynchUnit** hardware and the infrared camera up.

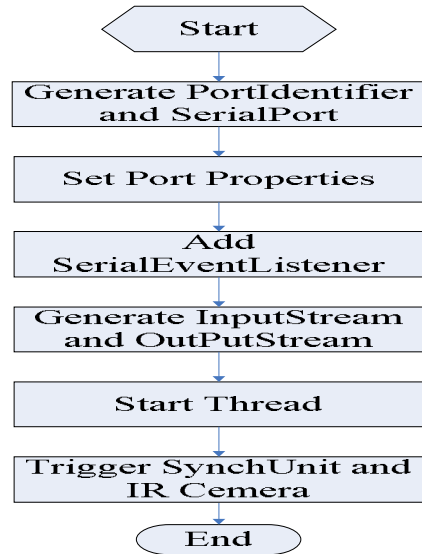


Figure 4.2.2.1.1 flow diagram of the init() method

When input data stream comes, SerialPortEventListener calls serialEvent() method automatically to handle serial Events. Figure 4.2.2.1.2 is the flow diagram of the serialEvent() method.

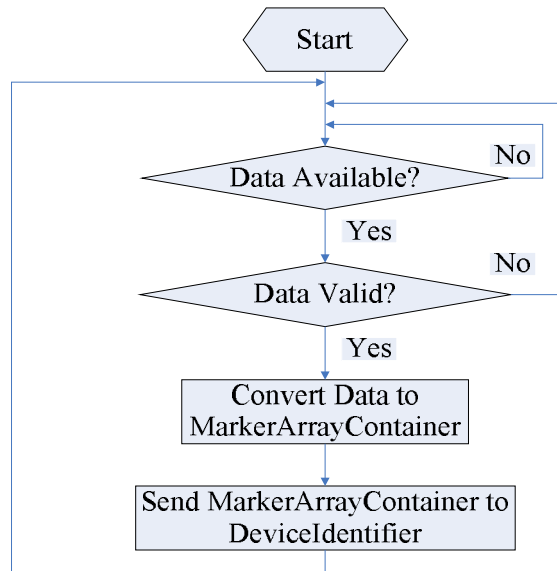


Figure 4.2.2.1.2 flow diagram of the serialEvent() method.

When a data comes from SynchUnit hardware through the serial communication port, the SynchUnitConnector object validate the arrived data in serialEvent() method. The legal data will be packaged into MarkerArrayContainer format and forward to DeviceIdentifier object.

4.2.2.2 Device Identification

1. Bit Code Algorithm

Every infrared input device in Qualitrack system has its unique eight bits identification code, which is called bit-code. The identification code is used to distinguish devices, so as to support more than one device work at the same time.

Correspondingly, a special bit-code identification algorithm is used in Qualitrack system. The core of this algorithm is the two rigorous bit-code selection constraints which will be mentioned in the following context.

Conventionally, the host computer software (like the camtraker program here) has to analyze n camera frames to identify a device. Hence, the real output tracking update rate would drop to the system tracking frame rate divided by n . To solve this problem, Constraint 1 is involved. Constraint 1, only one 0 bit is allowed between two 1 bits. Under this condition, when a device enters the view of the infrared camera, the camtracker program waits for eight frames to identify it (Initialization phase). But for every subsequent frame, the device position is updated whenever its bit-code is 1 for a frame. Hence the update rate only drops to half the system tracking frame rate.

Another problem is that we suppose many devices are used in parallel, and then they will all be active in the same camera frame. If two devices are very close to each other, it will be hard to distinguish them. So Constraint 2 is that the bit-code must be chosen as few as devices have a 1 bit at the same bit position.

After eight bits bit-code, there are two more status bits. They can be used for example to check if a button is pressed.

Obviously, this algorithm enhances the output of the tracking update rate effectively. The only shortcoming is that there isn't any mathematics formula to classify it until now. This will be an important future work definitely.

2. Device Identification Implementation

DeviceIdentifier class identifies infrared input devices, updates device position, orientation, status, and generates TUIO events.

The center method of DeviceIdentifier class is the run() method. It implements all the device identification functionality in a thread loop. And hence it works during the whole tracking life cycle. Figure 4.2.2.2.1 is the flow diagram of the

run() method.

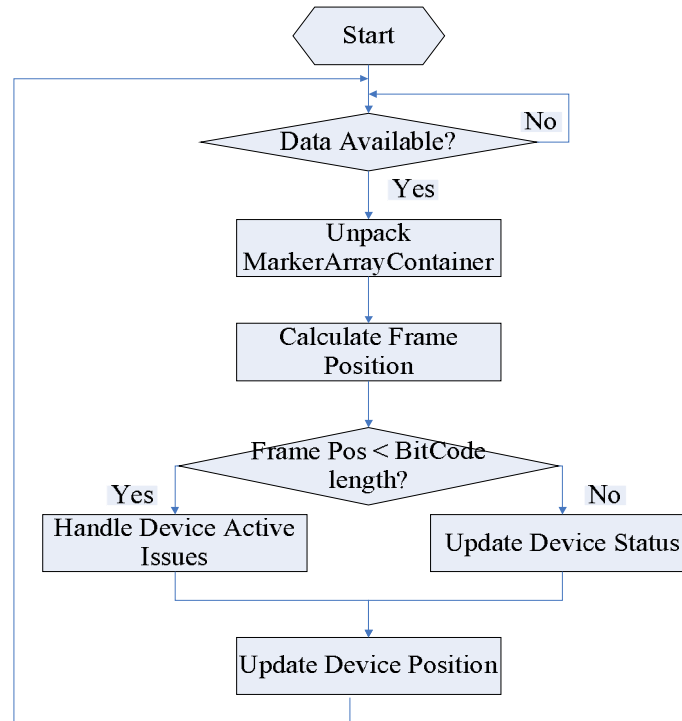


Figure 4.2.2.2.1 flow diagram of the **run()** method.

When the **DeviceIdentifier** object receives camera frame data, it calculates the frame position. If the arriving one is an identification frame, the **DeviceIdentifier** object will generate “Active Device Events”. If the arriving frame is a status frame, the **DeviceIdentifier** object will generate “Update Device Status Events”. Regardless of the frame type, the position of the infrared devices will always be updated.

4.2.2.3 Calibration Algorithm

When an infrared point is captured by the camera, its coordination is noted within the camera coordination system. But the logic coordination system of the display device is different from the camera. In order to present the position of the infrared point logically, it is essential to transform point coordination between the above two coordination systems. This procedure is called calibration.

The most common calibration algorithms are the Two Points Calibration Algorithm and the Three Points Calibration Algorithm. Both of the two algorithms are used in Qualitrack system. They can be shifted by change the calibration mode.

The following is the formula of the Two Points Algorithm. We define that the coordination of the left top corner as (ltx, lty) and the coordination of right bottom corner as (rbx, rby) in camera coordination system, then

$$\begin{aligned}\text{ratio}_x &= (\text{rbx} - \text{ltx}) / \text{screen width} \\ \text{ratio}_y &= (\text{rby} - \text{lty}) / \text{screen height} \\ X &= X^* \text{ratio}_x + \text{ltx} \\ Y &= Y^* \text{ratio}_y + \text{lty}\end{aligned}$$

Here, (X,Y) is the point coordination in display coordination system.

Three Points Calibration Algorithm is more complex but accurate than Two Points Calibration Algorithm. We define that the point coordination in camera coordination system as (Xc,Yc), and define it as (X,Y) in display coordination system. Then

$$\begin{aligned}X &= AX_c + BY_c + C \quad (1) \\ Y &= DX_c + EY_c + F \quad (2)\end{aligned}$$

Since we samples three points, so we have the following six equations.

$$\begin{aligned}X_1 &= AX_{c1} + BY_{c1} + C \\ X_2 &= AX_{c2} + BY_{c2} + C \\ X_3 &= AX_{c3} + BY_{c3} + C \\ Y_1 &= DX_{c1} + EY_{c1} + F \\ Y_2 &= DX_{c2} + EY_{c2} + F \\ Y_3 &= DX_{c3} + EY_{c3} + F\end{aligned}$$

After synthesize the above equations, we can get the coefficients A, B, C, D, E and F.

$$\begin{aligned}K &= (X_{c1} - X_{c3})(Y_{c2} - Y_{c3}) - (X_{c2} - X_{c3})(Y_{c1} - Y_{c3}) \\ A &= ((X_1 - X_3)(Y_{c2} - Y_{c3}) - (X_2 - X_3)(Y_{c1} - Y_{c3})) / K \\ B &= ((X_{c1} - X_{c3})(X_2 - X_3) - (X_{c1} - X_{c3})(X_{c2} - X_{c3})) / K \\ C &= (Y_{c1}((X_{c3}X_2 - X_{c2}X_3) + Y_{c2}(X_{c1}X_3 - X_{c3}X_1) + Y_{c3}(X_{c2}X_1 - X_{c1}X_2))) / K \\ D &= ((Y_1 - Y_3)(Y_{c2} - Y_{c3}) - (Y_2 - Y_3)(Y_{c1} - Y_{c3})) / K \\ E &= ((X_{c1} - X_{c3})(Y_2 - Y_3) - (Y_1 - Y_3)(X_{c2} - X_{c3})) / K \\ F &= (Y_{c1}(X_{c3}Y_2 - X_{c2}Y_3) + Y_{c2}(X_{c1}Y_3 - X_{c3}Y_1) + Y_{c3}(X_{c2}Y_1 - X_{c1}Y_2)) / K\end{aligned}$$

Substituting these coefficients into equation 1 and 2, we will get the point coordination (X, Y) in the display coordination system.

4.2.2.4 Compose and Forward TUIO package

Since the usual display refresh rate of a screen or a projector is 60Hz, while the tracking update rate of Qualitrack system is rather high than that, if we forward the input data directly to the display application, it will waste a lot of input data due to the low display refresh rate of the display equipment. In this project, we optimized Qualitrack system by using two successive input data to calculate a middle point so as to make the system more accurate. Figure 4.2.2.4.1 is the middle point calculation algorithm.

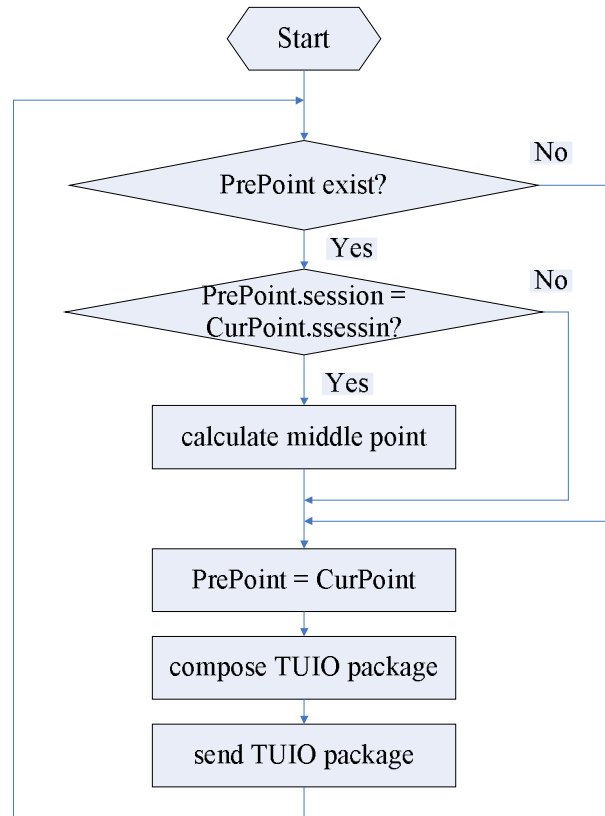


Figure 4.2.2.4.1 compose TUIO package with middle points

If the previous point is not exist or the session ID of previous point is not the same with the current point, it means the current point is the first point in the current session. Then it will be composed into TUIO package and sent to the TUIO application directly. If there is a matched previous point, then the information of previous point and the current point, such as position coordination, speed, acceleration, and so on, will be used to calculate a middle point between the previous point and the current point. This middle point will be assembled into TUIO package and sent to the TUIO application. At the same time, the previous point will be refreshed by the current point.

4.2.3. User Study Applications: Writing Drawing App and Air Hockey App

4.2.3.1 Writing and Drawing Application

The writing and drawing application is designed for the infrared pen. This application is built based on the TUIO reference implementation which is part of the reactIVision framework. Its graphic user interface is developed with Java Swing.

The most important part of this program is called work area component. It is a Java Swing component extends from Java Component class and it is a TUIO client component which takes charge of receiving and parsing TUIO package. After receiving the TUIO package from the camtracker program, the work area component decode the TUIO package and update the screen. Figure 4.2.3.1.1 is the data flow chart of the work area component.

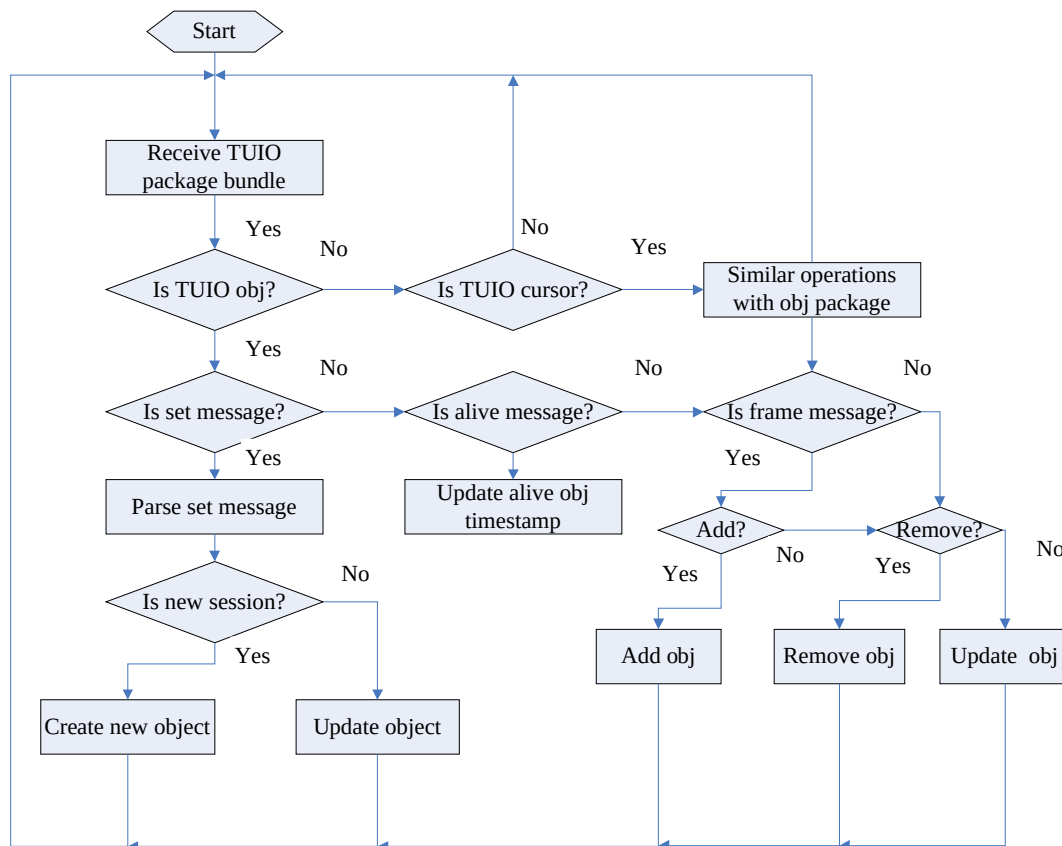


Figure 4.2.3.1.1 TUIO client component data flow chart

After the TUIO client component receives the TUIO package bundle, it will check

the arriving one is a TUIO object package bundle or a TUIO cursor package bundle. Then it will check the message type. If it is a set message, the TUIO client component will parse this message and assign its information into some specific variables. If this set message belongs to a new session, then a new TUIO object will be created. Otherwise, an existing TUIO object within the same session will be updated. When an alive message comes, the timestamp of an object within the same session will be updated. If the received message is a frame message, TUIO client will scan the label of the frame message, and do relevant operation. The process of a TUIO cursor package bundle is quite similar with a TUIO object package bundle.

4.2.3.2 Air Hockey application

The AirHockey_App is a C++ program developed base on the OpenFrameworks. OpenFrameworks is an open source C++ library. OpenFrameworks is based on some well known libraries, such as OpenGL, openCV and so on. It offers us a lot useful libraries with more convenient and appropriate call interface than the base libraries. It provides a nice framework for building up a game. Figure 4.2.3.2.1 shows the structure of this framework.

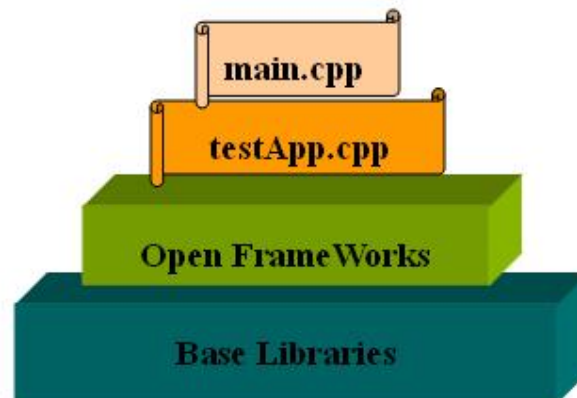


Figure 4.2.3.2.1 structure of OpenFrameworks

The main.cpp file is the starting point of the applications. It declares the resources used in the program, such as OpenFrameworks, and start the program. The testApp.cpp file is the center class in this framework. It contains the business logic of a specific application. There are three important methods in this class. The setup() method is used to initialize resources, for instance objects and variables. It is only called once in the program. The update() method is called continuously by a background loop. In this method, the objects and variables update their status. The draw() method is used to draw the screen according to the latest resources status.

After receiving the TUIO package from the camtracker program, this program decodes the TUIO packages and updates the screen according to the new data.

Figure 4.2.3.2.2 shows the data flow of the Air Hockey Game application program

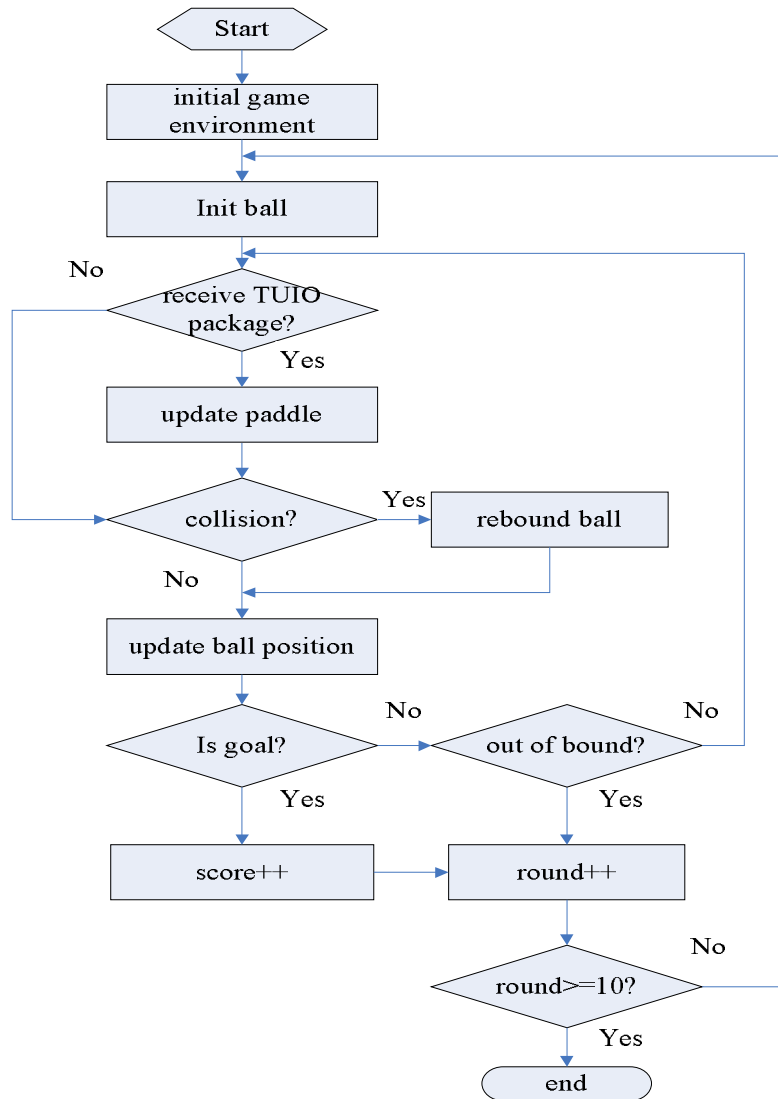


Figure 4.2.3.2.2 data flow of Pong Game application

The program environments, such as the goal gate position and so on, are only initialized one time at the beginning of the game. But the ball will be initialized in every new round. When a new TUIO packaged bundle is received, the status of the paddle will be updated. If the ball hits the paddle or the walls, it will be rebounded. Both the x and y speed of the ball will be reversed. If the position of the ball is inside the goal gate, it means there is a goal. Then the player will get a score. No matter the player gets a score or the ball flies out of boundary, the current round will be finished immediately. If the round counter is greater than ten rounds, game is over. Otherwise, a new round will start.

4.3 New Table Top Device: Magnifier and Color Filter

There are only two infrared devices exist in Qualitrack system by the time we took over it. They are the infrared pen and the infrared handle. To enrich Qualitrack system, we developed two new devices for Qualitrack. They are the magnifier and the color filter. The magnifier is used to enlarge the image. The color filter is a special visual assistant tool designed for the colorblind people. Both of the two devices are based on the same hardware. But they were design and implemented with two different software solutions.

4.3.1 Magnifier Application

The Magnifier Application is developed by java. It is designed as an independent java component so that can be reused in other applications. Figure 4.3.1.1 shows its business logic.

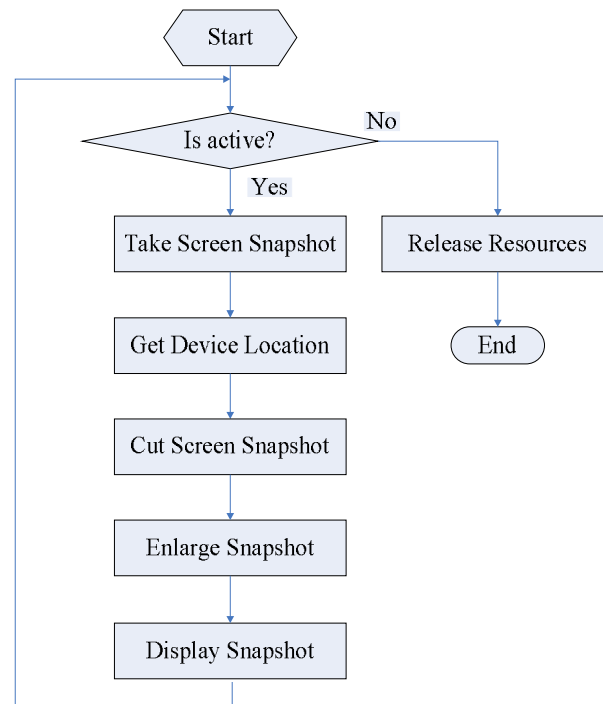


Figure 4.3.1.1 magnifier application algorithm

The “magnifier” application communications with the “camtraker” program under TUIO protocol. As long as the magnifier is on the table surface, it will be recognized as active status. Once the position of the magnifier is updated, it will take a snapshot of the screen acceding to the coordination received from the “camtracker” in real time. Then the magnifier enlarges the snapshot and

displays the enlarged image inside its frame.

4.3.2 Color Filter Application

Color blindness is color vision deficiency, which is the inability to perceive differences between some of the colors that others can distinguish. The frequency of color blindness is fairly high among males: 8% among Caucasian, 5% among Asian, and 4% among African.^[18]

Generally, there are two methods to avoid color confusion. The first method provides an additional clue which is not relying on color information. For example, usually the color of a visited web link is red, while the unvisited one is blue. Obviously, color blind viewer can not distinguish this difference by color. To solve this problem, we can design the webpage as following. The link status is showed as a prompt message, when the mouse cursor is hovering on a web link. The second method is using high degree contrast color combination in the user interface. However, colors that are seemingly contrasting and perceptible to a normal color viewer can appear less so to a color blind viewer. When color is used as the primary means to encode information, people with color deficits may not perceive the information as intended.^[19] It is impossible to let normal color viewer and color blind viewer absolutely experience each other's feeling about the same color. So it is very hard to find the best combinations which can express the same color information to the two groups at the same time.

Meanwhile, a table top system, as a platform, can not and should not change the user interface design of the third party application which runs on it. But from this point of view, we can help the color blinder viewers works easier by designing a visual assistant device on this platform. An efficient and effective approach to solve the color confusion problem is to take a snapshot of the environment (a "screen grab") and remove the color so you are looking at it in grayscale.^[20] The color filter device is designed an implanted acceding to this method.

The algorithm of the "color filter" application is quite similar with the "magnifier" application. The only difference is the "magnifier" enlarges the snapshot, while the "color filter" application converts the snapshot to gray scale image. Of course, we also can combine the magnifier and color filter functionalities together. Then we will get a color filter magnifier.

In the study of the perception of color, one of the first mathematically defined color spaces was the CIE 1931 XYZ color space, created by the International Commission on Illumination (CIE) in 1931.^[21] Figure 4.3.2.1 is the CIE 1931 color space chromaticity diagram which is based on the human eye perception of chromaticity. From the human eye's point of view, the percentage of red,

green and blue in a white light is different. Thus, we need to add different weight value to different color channel so as to mix a gray scale which is similar with gray level in human's eyes.

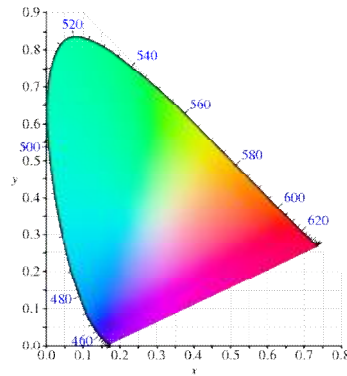


Figure 4.3.2.1 CIE 1931 color space chromaticity diagram [21]

International Telecommunication Union (ITU) defines several recommendation standards for gray scale translation. The most popular ones are ITU-R BT.601 and ITU-R BT.709. Formula 1 is gray-scale transformation formula in ITU-R BT.601. In this formula, R is short for red, G is short for green, B is short for blue, and Y is the gray scale.

$$Y = 0.298912 * R + 0.586611 * G + 0.114478 * B \quad (1)$$

Usually, we do not need so accurate value in programs, so we accurate the coefficient to three figures behind decimal point, like formula 2.

$$\text{Gray} = 0.299 * R + 0.587 * G + 0.114 * B \quad (2)$$

The gray-scale transformation formula of ITU-R BT.709 is showed in formula 3.

$$Y = 0.212649 * R + 0.715169 * G + 0.072182 * B \quad (3)$$

Figure 4.3.2.2 is the gray scale result of based on ITU-R BT.601 standard.

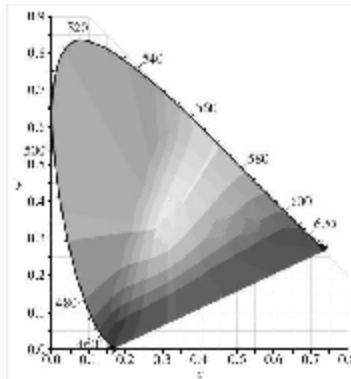


Figure 4.3.2.2 gray scale result of based on ITU-R BT.601

5. User Study Experiment

A three tasks user study experiment is designed to find out how the tracking update rate influences user experience in Qualitrack system.

5.1 Terminology Definition

Tracking Update Rate:

The number of frames which can be captured by Qualitrack system within one second

5.2. Participants

Two female and eight male volunteer participants are involved in this user study experiment. All of them are university students;

5.3. Apparatus

5.3.1 Hardware

Hardware for the experiment consists of

- a) **Infrared pen:** one infrared LED is mounted at the tip of the IR pen. It can be used to write and draw when the tip switch behind the LED is press.
- b) **Infrared air hockey paddle:** three infrared LED are mounted in the IR paddle so as to distinguish the orientation of the paddle.
- c) **Infrared camera:** ProReflex MCU240 is used in Qualitrack system. Its capture update frequency is up to 250Hz.
- d) **SynchUnit:** Olimex SAM7-P256 development board with AT91SAM7S456 micro controller is used to trigger and synchronies all devices.
- e) **Host computer:**
 - u CPU: Intel Core2 Duo E8400 (3.0GHz)
 - u Video Card: NVIDIA Geforce 9300GE (256M DDR2 video memory)

- f) **Projector:** ProjectionDign FL32 is used. Its resolution is up to 1920 x 1200.
- g) **Screen Table:** a horizon table with a 100cm x 75 cm hole in its center. A brown optical glass covers the hole as the screen.

5.3.2 Software

The Java program, "camtracker", was run on the host computer. It takes charge of receiving data from SynchUnit, processing input data into TUIO package and forwarding the TUIO packages to TUIO clients. The writing and drawing task user study application was programmed by Java. The Air Hockey Game task user study application was programmed by C++. Both the two user study applications communicate with the "camtracker" program with TUIO protocol.

5.3.2.1 Writing Drawing Application Program

This is a Java application for the writing and drawing tasks of the user study experiment. Java Swing is used to build the graphic user interface. There are three graphic user interfaces in this application program.

The first one is used for the writing task, like figure 5.3.2.1.1.



Figure 5.3.2.1.1 user work interface of user study application for the writing task

This user interface can be divided into two mainly parts. In the left, there is the information area. In the right, there is the work area.

The information area can be divided into four sections. The first section is the system instruction section, which shows the software help information. Under it, there is the task instruction section. The user study task instructions and attentions are showed here. The following is the OK button. After the participants finishing their work, they can shift the infrared pen into mouse mode and use it to press the OK button. Then the program will save their work as a JPEG format picture into the hard disc driver in the host computer automatically. There is also another way to save the user work by press the Enter key in the key board. The last section is the status section. After the participants save their work, the program will notice them in the status section, saying that their work has already been saved in the hard disc driver.

In the work area, the participants are demonstrated with two sentences. Both of them are "I love Qualitrack", but one is ligatures, the other is written by block's letter. The participants can write their sentences underneath the sample sentences with the infrared pen. If the user made some big mistakes, they can press F3 to undo one step of their operation or press F4 to clean the whole work area. By press F1, this interface can be shift between the window mode and the full screen mode.

Figure 5.3.2.1.2 is the graphic user interface for the drawing task.

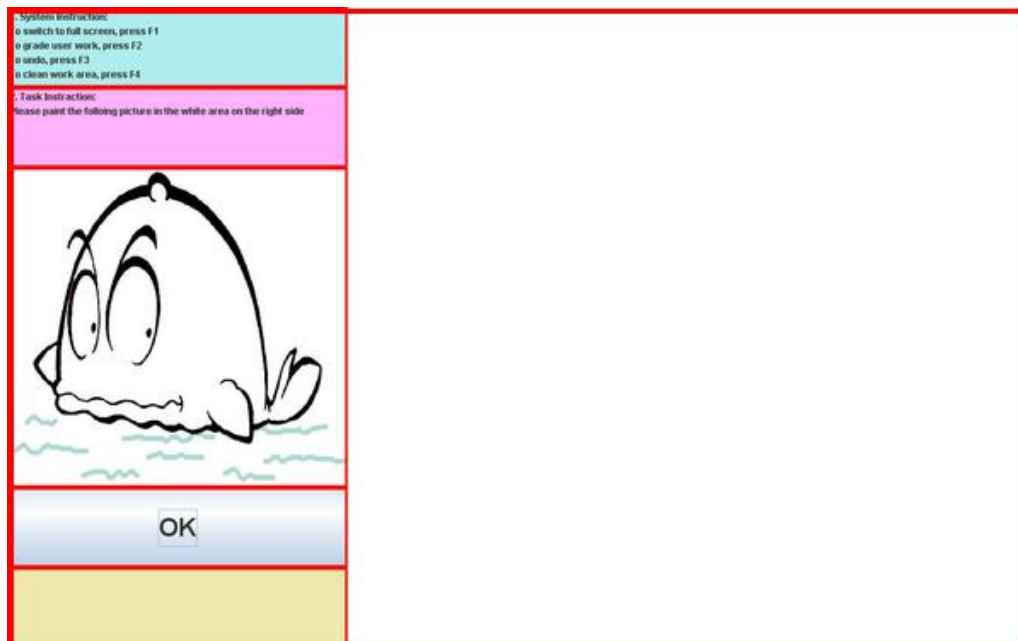


*Figure 5.3.2.1.2 user work interface of user study application
for the drawing task*

It is similar with the one for the writing task. There is an additional sample picture section in its information area. A sample picture is loaded by this program automatically whenever the application runs.

The participants can draw their picture in the work area with the infrared pen. After they finish their work they can save their work by pressing the OK button as well.

By press F2, we can shift to the system grading user interface. It is used for the participants to grade the system performance. Figure 5.3.2.1.3 is the system grading graph user interface.

Instruction:
Please grade the system's
reaction speed
from 1 to 5
(1 is the worst and 5 is the best)
You may give the same grade more
than once !

NO Picture

1 2 3 4 5

NO Picture

1 2 3 4 5

NO Picture

1 2 3 4 5

NO Picture

1 2 3 4 5

Figure 5.3.2.1.3 system grading graph user interface.

This interface can be divided into two parts as well. In the left, there is the instruction area. In the right, there is the grading area.

The grading instruction and attentions is showed in the instruction area. The participants will be asked to grade the system four times from four different aspects. Each time, the grading topic will be displayed with red color and big font in order to remainder the participants what they are grading for.

This program loads the user work pictures into the grading area automatically. The participants can grade their work by pressing the grading button under each user work picture. The grade button will change its color to red immediately after being pressed. At the mean while the other buttons within the same group will become disabled automatically so that the user can not grade more than

once for the same feature of the same user study task trail by mistake. The grading result will be record into a log file in the hard disc driver automatically. These data will be used for the user study analysis.

5.3.2.2 Air Hockey Game Application Program

The air hockey game application is a C++ application for the air hockey game task of the user study experiment. This game is processed in ten rounds. A ball is served from the goal at the beginning of each round from random positions with random orientation. The user's task is to bat the ball into the goal with an infrared air hockey paddle. The ball will rebound back if it hits the white borders. Whenever the user gets a goal or misses the ball, the current round is finished and the next round will start in 3 seconds. Figure 5.3.2.2.1 shows the interface of the air hockey game application program.

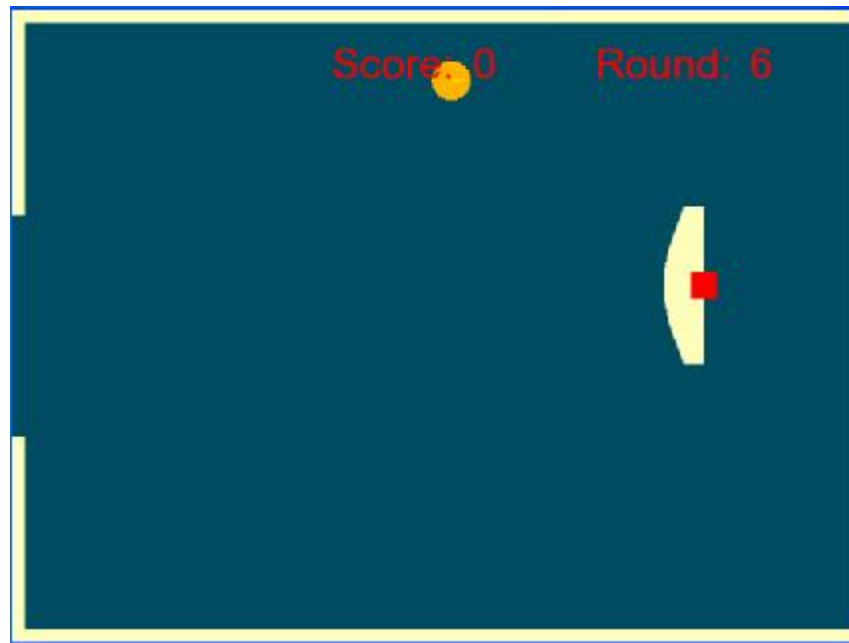


Figure 5.3.2.2.1 user study application for the air hockey game task

5.4 Procedure

The user study consists of three tasks:

- (a) Handwriting
- (b) Drawing
- (c) Air Hockey Game

Participants perform all three tasks over two sessions. The first session is a

warm-up session, which takes five minutes. In this session the users are demonstrated how to do the following task and free to do anything they want in order to get familiar with the system and the task. The second session is the experiment session.

Originally, the system tracking update rate can be adjusted from 1Hz (the ideal lower boundary, although this value points is no meaning in practice) to 250Hz (the physic limitation of the SAM7-P256 microcontroller). In our user study experiment, we bound the range from 100Hz to 250Hz with the increasing step at 50Hz in every trail. Namely, we will test 100Hz, 150Hz, 200Hz and 250Hz. So every participant should repeat each task four times.

After the participants finish the four trials in each task, they are required to grade their felling from the following three different aspects:

- I system reaction speed
- I system reaction consistency
- I system overall performance

The grade is designed from 1 to 5 for all the three aspects.

- I 1 means not satisfied at all;
- I 2 means not satisfied;
- I 3 mean not good and not bad;
- I 4 means satisfied;
- I 5 means very satisfied.

Above all, a four fully within-participants repeated measures design was used for each task. The independent values are system tracking update rate (100Hz, 150Hz, 200Hz and 250Hz). The dependent value is user grading, from 1 to 5. Thus, for each task, we obtain:

- I 4 trials with Task 1
- I 4 trials with Task 2
- I 4 trials with Task 3

We assume that the participants use five minutes in each trail averagely, then each participant will spend twenty minutes within each task and sixty minutes totally for the three tasks.

5.4.1 Handwriting Task

Two sample sentences are displayed in the work area. They are the same sentence "I love Qualitrack". One is ligature. The other is block's letter. The participant is instructed to aim for both speed and accuracy, when writing the sentences underneath the two sample sentences with the infrared pen. The participant is required that if a mistake was made, he or she is to ignore it and

continue with the sequence.

After finish writing, the participant is asked to switch the infrared pen to the mouse mode and use it to press the OK button. Then, the participant's work will be saved in the hard disc driver of the host computer automatically. In the new trail, the system will be set at another testing tracking update rate randomly without telling the user which update rate it will work at, in case that the participant will predict the system performance.

After the participant finishes all the four trials, by press F2, the grading user interface is launched. The participant's work will be load into the screen in parallel so as to the participant can grade them. The participant grade the their experience on the system's reaction speed, system reaction consistency and system overall performance from 1 to 5. for example, if the system generate the scratch immediately after the participants wrote without any human perceptible delay, then the system reaction worth 5. On the contrast, if the scratch is generate after a unbearable delay, then the system reaction should be grade to 1. If the scratch is a smooth and continuous line, then the system reaction consistency is 5. If it is a sharp poly line, then the system reaction consistency is 1. The last but not the least, the user is asked to give the overall grade to their experience of the system's entire performance.

5.4.2 Drawing Task

A simple picture is projected at the sample area of the drawing task user study application. The participant is asked to draw it at the working area with the infrared pen.

After finish drawing, the participant is asked to switch the infrared pen to the mouse mode and use it to press the OK button. Then, the participant's work will be saved in the hard disc driver of the host computer automatically. In the new trail, the system will be set at another testing tracking update rate randomly without telling the user which update rate it will work at, in case that the participant will predict the system performance.

After the participant finishes all the four trials, by press F2, the grading user interface is launched. The participant's work will be load into the screen in parallel so as to the participant can grade them. The participant grade the their feeling on the system reaction speed, system reaction consistency, and system overall performance from 1 to 5. The meaning of the three questions is the same with the writing task.

5.4.3 Air Hockey Game Task

A ball will be served from the gate which is at the top center of the screen. The width of the gate is one thirds of the screen width. The participant is asked to uses the infrared air hockey game paddle to beat the ball back to the gate. If the participant succeed, he or she will get 1 score. When the participant gets a goal or the ball flies out of boundary, a new round will start. The ball will be served from a random position near the gate at random orientation and velocity. There are three second break between each round so that the user can be ready. The whole trail takes lasts for ten balls.

The participant will grade their experience whenever the task is finished a trail immediately. The participant is required to grade his or her feeling on the system reaction speed, system reaction consistency and system overall performance from 1 to 5. In this task, the meaning of system reaction speed implies the reaction speed of the paddle image when the participant moves the infrared paddle. And the system consistency here means if the image of the paddle is continues and stable then it worth 5. On the contrast, if the image of the paddle twinkles obviously, then the system reaction consistence is bad.

In the new trail, the system will be set at another testing tracking update rate randomly without telling the user which update rate it will work at so that the participants will not be influence by their own prediction.

5.5 User Study Data Analysis

Appendix 1 is raw data of the user study experiment.

In drawing task, the differences between system tracking update rate were statistically significant for system reaction speed ($F_{3, 36} = 16.610$, $P < .001$), for system consistency ($F_{3, 36} = 10.987$, $P < .001$) and for over all grade ($F_{3, 36} = 11.095$, $P < .001$).

Figure 5.5.1 shows the bar chart of the average grade in the drawing task.

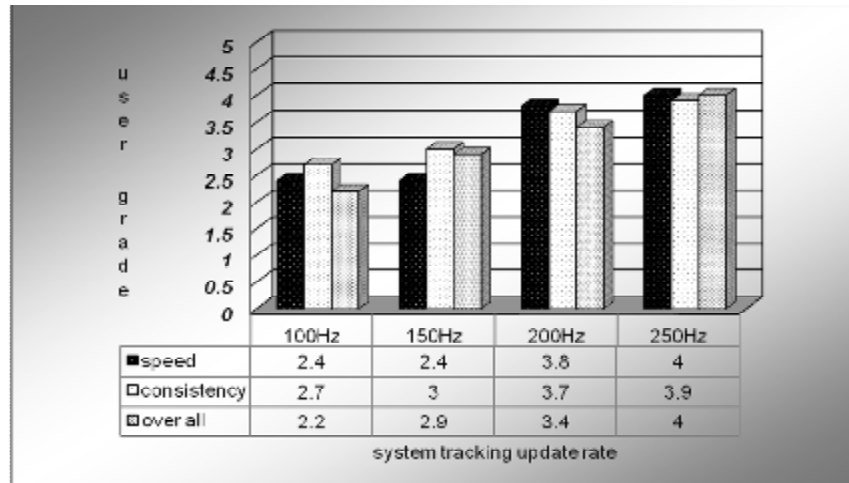


Figure 5.5.1 bar chart of the average grade in drawing task

In drawing task, Qualitrack system got the highest user grade on system reaction speed, system consistency and over all user experience at 250Hz. But from the above bar chart we can discover that the user grade gap between 200Hz and 250Hz is not so obvious than the one between 150Hz and 200Hz. Namely, the user experience enhance a lot over 200Hz in drawing task.

In writing task, the differences between system tracking update rate were statistically significant for system reaction speed ($F_{3, 36} = 7.0548$, $P < .001$), for system consistency ($F_{3, 36} = 5.122$, $P < .005$) and for over all grade ($F_{3, 36} = 9.321$, $P < .001$).

Figure 5.5.2 shows the bar chart of the average grade in the writing task.

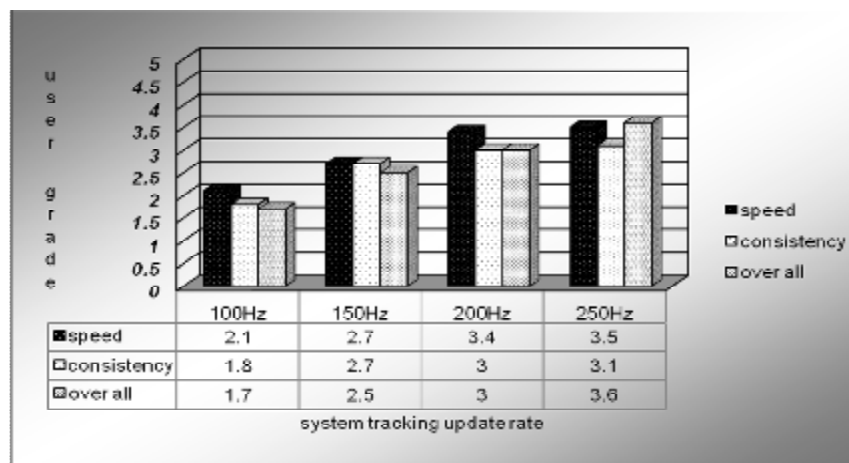


Figure 5.5.2 bar chart of the average grade in writing task

In writing task, Qualitrack system still got the best user experience at 250Hz on all the three factors. But compare with the drawing task, the average user grade

is lower down in all the three testing conditions.

In air hockey game task, the differences between system tracking update rate were not statistically significant for system reaction speed ($F_{3, 36} = 1.9216$, ns), for system consistency ($F_{3, 36} = 1.8328$, ns) and for over all grade ($F_{3, 36} = 1.4019$, ns). It means that the differences between the four levels of system tracking update rate in user grade for each factors are due to chance. So, there is no meaning to discuss the result of the air hockey game task here.

Figure 5.5.3 shows the comparison between drawing and writing tasks.

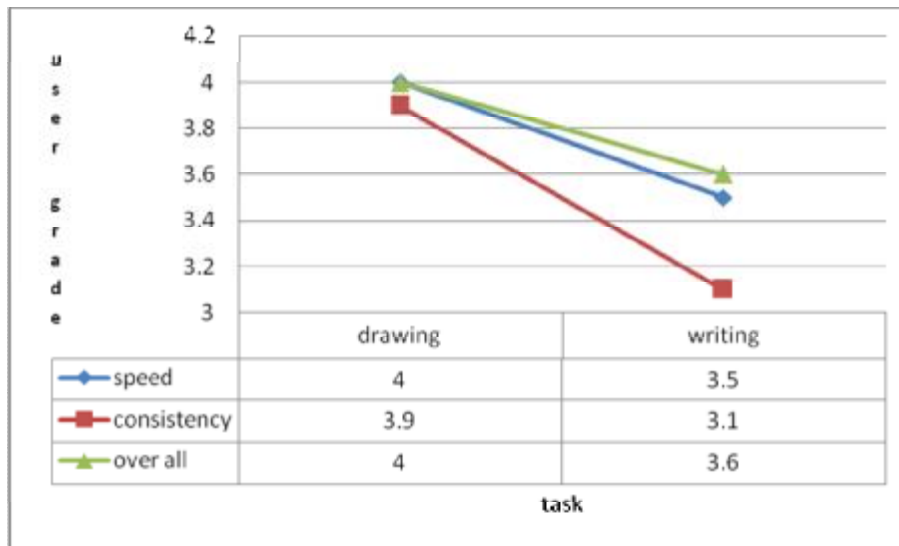


Figure 5.5.3 curve chart of the comparison among the task winners

From the above curve chart, we can see that Qualitrack system got obvious higher user experience grade on system reaction speed, system consistency and over all user experience factors in drawing task than writing. On the contrast, we can discover that the participants gave Qualitrack system the lowest grade on all the three factors in writing task, especially on system consistency feature. Namely, the result of the above comparison suggests that Qualitrack is good at drawing than writing.

6. Discussion

6.1 Discussion on Setting UP Qualitrack System

The first goal of this project is to reconstruct Qualitrack System. We know Qualitrack system more deeply during the procedure of rebuilding it, and found several existing problems in the original system. Here we discuss theses problems and our corresponding solutions in the following:

6.1.1 Static Calibration VS. Dynamic Calibration

The original Qualitrack used static calibration solution in its implementation of camtracker program. Namely, the same empirical calibrate parameter values were used all the time to calibrate the input devices.

The system arrangement, the relative distances and angles among the projector, camera and table, will influence the calibration accuracy of the whole system obviously. So it is very hard to find a set of responsive empirical calibration parameter values. Thus, it is not hard to imagine that the calibration accuracy of the original Qualitrack is really bad. Before this project, there isn't any user graphic interface application for Qualitrack system. Therefore, the former developers ignored this problem, since they couldn't see the result intuitively.

To solve this problem, we applied a dynamic calibration solution. Namely, we did a calibration test to get the fresh calibration parameter values before the core of the camtracker program started running. As a result of this dynamic calibration solution, the system calibration accuracy enhanced substantially.

We support the user two alternatives in order to make the new Qualitrack system friendly enough. The user can choose to do a dynamic calibration when the system starts or load the old experimental calibration setting data from the system resource file.

6.1.2 System Arrangement

During the procedure of setting up Qualitrack system, we encountered some problems with the system arrangement, which reduced the system performance of Qualitrack in some way.

First of all, due to the size of the ProReflex MCU240 infrared camera is too big

(242 × 97 × 133 mm) and too heavy (2.4 Kg) to be set vertically under the table surface, we have to use a 45 degree angle mirror to reflect the input infrared light to this camera. Thus, the quality of the mirror became a big threshold of the system accuracy.

Secondly, a brown color glass was used as our table top surface, namely the screen. In order to prevent the brown glass to be scratched by the hard tip of the infrared pan, we covered an extra normal plastic glass on it. However, the difference refractive indexes of the two kinds of glass cause the infrared light leave its expected track and decreased the system accuracy.

6.2 Discussion on New Input Devices

The second goal of this project is to create a new input device. A homocentric squares shaped hardware was developed around this goal. At the mean while, the magnifier application program and the color filter application program were developed for this new input device.

In the first version of the magnifier, the three plastic infrared LEDs scratch the table surface when the user drag it rather than move it. That noisy is really annoying and reduce the user experience a lot.

To solve this problem, we attach four soft pads in the four corner of this device to make the LEDs leave the table surface about one millimeter. Although the functionality and performance of this device is the same as before, the users' response enhance a lot just because the improvement of thus a small hardware design detail.

Most users thought the magnifier is really useful and natural. We expect the response from a real color blind person in the future. And we will try to find more proper material to build up the other input device so that the users can feel more comfortable working with our system.

6.3 Discussion on User Study Experiment

The last goal of this project is to carry out a user study experiment so as to discover the influence of the system tracking update rate on user experience with Qualitrack system.

The winner of both drawing and writing tasks is 250Hz. In wringing task Qualitrack system only got 3.6 score on over all user experience in the best condition. The highest user over all experience grades was generated in drawing task, but still only 4. Namely Qualitrack system still has a long distance to be

perfect. According to the result of this user study experiment, Qualitrack system needs to further enhance its tracking update rate. At the mean while, as we discussed in chapter 6.1.2, the arrangement of Qualitrack needs to be redesigned.

6.3.1 Writing VS. Drawing

From figure 5.5.3, we can discover that Qualitrack system performed worse in writing task than drawing task intuitively.

There are two reasons can explain this phenomenon. First of all, when the participants wrote, their scratch was shorter than drawing. In other words, the tip of the infrared pen left the table surface more frequently in writing task. Whenever the tip of the infrared pen touched or left the table surface, Qualitrack need eight frames to recognize this state change. So the system tracking update rate is decreased eight times during this procedure. Secondly, due to the participants are more familiar with writing than drawing in their daily life, their scratching speed is faster in writing task than drawing task. As a result of the above two reasons, it requires more critical system response time and scratch consistency performance when design a digital pen based table top system which aimed at writing operation.

6.3.2 Statistic Explanation on Air Hockey Game Task

In air hockey game task, our null hypothesis (H_0) was "There is no difference between the four levels of system tracking rate in system reaction speed, system consistency and user over all experience grade, of which formal express as " $H_0: X_1=X_2=X_3=X_4$ ". Our Alternative hypothesis (H_1) was " H_1 : There is at least one above equation doesn't exist" After Analysis of Variance (Anova), we found that all for the three factors were non- statistic significant. Namely we do not have enough reason to deny the null hypothesis according to our current data. And the difference observed between system tracking update rates is likely due to chance, rather than the test condition. This could be the result of small sized sample. We can do this experiment by enlarging the data size and see if it will works better in the future

7. Conclusion

In this project, we reconstructed a high speed table top system successfully based on some existing work. At the beginning of this project, all the old hardware are lost or damaged. Moreover we were lack of detailed system specification document. Thus it took us quite a long time than we could imagine rebuilding Qualitrack system. Form the procedure of setting up Qualitrack system, we found the following conclusions:

1. Dynamic calibration is essential in Qualitrack system.
2. The accuracy of Qualitrack system is influenced by the arrangement.

To enrich the input devices of Qualitrack system, we created two new devices: the magnifier and the color filter. Most of the system user thought the feature of the magnifier is quite nice and useful. At the mean while we discovered that the material of an industrial product influences the users' experience quite a lot.

A three task user study experiment was design and processed to find out the influence on the user experience by the system tracking update rate. Ten volunteer participants are involved in this user study. From the experiment data we get the following conclusions:

1. System performance can be enhanced obviously along with increasing the tracking update rate in a table top system. This conclusion is more obvious in low update rate range than the high update rate range.
2. It requires more critical system performance in a digital pen based table top system which aiming at writing operation than drawing.

Moreover, from this project, we learned that user experience should be kept in mind through the whole process of designing, implementing and evaluating a computer system. Due to our technique education background, we usually didn't think over this aspect enough before we taken this project. "Think much of user experience" is the most valuable knowledge we got form this project and we will got the benefit from it our whole life.

8. Future Work

8.1 About Qualitrack System

- 1. Formulate the bit-code algorithm in a mathematical way.**
- 2. Redesign the arrangement of Qualitrack system so as to enhance the system's accuracy and sensitivity.**
- 3. Use more powerful electronic development board as the synchUnit in order to enhance the system tracking update rate.**
- 4. Create more input devices.**
- 5. Develop communication functionality so that to support remote collaboration work.**

8.2 About User Study

- 1. Enlarge user study participant group size.**
- 2. Evolve more Input devices into the user study**
- 3. Carry out the same user study experiment on other high speed table top system so as to compare the defenses between similar systems.**
- 4. Analysis the participants' behavior from psychology point of view.**

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Appendix

Appendix 1 Original User Study Data

				drawing task 100Hz						
	Subject1	Subject2	Subject3	Subject4	Subject5	Subject6	Subject7	Subject8	Subject9	Subject10
speed	2	3	3	3	2	2	2	2	2	3
consistency	3	3	3	3	4	2	2	3	2	2
influence	3	2	2	3	2	2	1	1	3	2
over all	3	3	2	3	2	2	1	1	3	2
				drawing task 150Hz						
	Subject1	Subject2	Subject3	Subject4	Subject5	Subject6	Subject7	Subject8	Subject9	Subject10
speed	2	3	3	3	2	3	1	1	3	3
consistency	2	2	3	3	4	3	4	4	2	3
influence	2	3	3	3	3	4	2	2	3	3
over all	2	4	3	3	3	4	2	2	3	3
				drawing task 200Hz						
speed	3	4	4	4	3	4	5	5	3	3
consistency	5	3	3	3	4	4	4	4	3	4
influence	4	3	3	4	3	4	4	5	3	4

over all	5	3	3	3	3	4	3	3	3	4
				drawing task 250Hz						
	Subject1	Subject2	Subject3	Subject4	Subject5	Subject6	Subject7	Subject8	Subject9	Subject10
speed	4	4	5	4	4	4	4	4	3	4
consistency	4	4	5	4	4	4	3	4	3	4
influence	4	3	4	3	5	4	3	3	3	4
over all	4	4	5	4	5	4	3	4	3	4
				wrting task 100Hz						
	Subject1	Subject2	Subject3	Subject4	Subject5	Subject6	Subject7	Subject8	Subject9	Subject10
speed	3	4	3	2	2	1	2	2	1	1
consistency	4	2	2	2	2	1	1	1	2	1
influence	3	2	2	2	2	1	1	1	2	1
over all	4	1	2	2	2	1	1	1	2	1
				wrting task 150Hz						
speed	3	3	3	3	2	3	3	3	2	2
consistency	3	3	2	3	2	4	3	3	3	1
influence	2	3	2	2	2	3	2	2	3	1
over all	3	3	2	3	2	4	2	2	3	1
				wrting task 200Hz						
	Subject1	Subject2	Subject3	Subject4	Subject5	Subject6	Subject7	Subject8	Subject9	Subject10
speed	3	3	4	4	3	3	4	4	3	3

consistency	3	3	3	3	3	3	3	3	4	2
influence	2	2	3	3	3	3	3	3	4	2
over all	3	3	3	3	3	3	3	3	4	2
				wrtng task 250Hz						
	Subject1	Subject2	Subject3	Subject4	Subject5	Subject6	Subject7	Subject8	Subject9	Subject10
speed	3	4	5	3	5	4	3	3	2	3
consistency	3	3	4	3	4	5	2	2	2	3
influence	4	3	4	3	4	5	3	3	3	3
over all	3	3	5	3	5	5	3	3	3	3
				game task 100Hz						
	Subject1	Subject2	Subject3	Subject4	Subject5	Subject6	Subject7	Subject8	Subject9	Subject10
speed	3	4	4	2	3	3	1	1	4	2
consistency	4	4	4	2	4	3	1	1	3	2
influence	5	3	3	3	3	3	2	2	4	2
over all	5	3	4	3	3	3	2	2	4	2
				game task 150Hz						
	Subject1	Subject2	Subject3	Subject4	Subject5	Subject6	Subject7	Subject8	Subject9	Subject10
speed	4	5	5	3	4	2	3	3	3	3
consistency	3	3	4	3	4	2	2	2	4	3
influence	4	3	5	3	4	3	2	2	3	3
over all	4	3	5	3	4	3	3	3	4	3

				game task 200Hz						
	Subject1	Subject2	Subject3	Subject4	Subject5	Subject6	Subject7	Subject8	Subject9	Subject10
speed	5	3	4	3	3	4	2	2	3	3
consistency	4	4	3	2	4	4	3	3	2	3
influence	5	3	3	3	4	4	3	3	3	3
over all	5	3	3	3	4	4	3	3	3	3
				game task 250Hz						
	Subject1	Subject2	Subject3	Subject4	Subject5	Subject6	Subject7	Subject8	Subject9	Subject10
speed	3	4	4	3	4	3	4	4	3	4
consistency	3	4	3	3	5	3	4	4	4	4
influence	4	3	3	3	4	4	5	4	3	4
over all	4	4	4	3	5	3	4	4	3	4

Appendix 2 Tips to set up Qualitrack System (Software Part)

1. About SyncUnit

Question 1: How can I know the *Olimax Sam7-p256 development board* works or not?

Answer: Run the example code `demo_at91sam7_p64_blink_flash` on Olimax Sam7-p256 development board. Details please read <<ProReflex MCU Technical Reference>>.

Question 2: How can I know the double end camera cable works or not?

Answer: Use Docklight to test the double end serial cable. Pay attention to set the baud rate within 19200 in dock light. Docklight can't support a baud rate over it. Details about Docklight, please read << Docklight V1.9 User Manual 05/2009 >>

2. About Camtracker Program

Question 3: How to set up RXTX?

Answer:

- I Unzip the "rxtx-2.1-7-bins-r2.Zip" file which is under the root folder of the camtracker program.
- I Copy the "rxtxSerial.dll" file into your "%JDK_HOME%/bin/" folder.
- I Copy the "RXTXcomm.jar" file into your "%JDK_HOME%/jre/lib/ext" folder.
- I eclipse project property—>Java Build Path->Libaray->Add External JARs, add "RXTXcomm.Jar" into the camtracker project.

Question 4: What is the difference between TUIO cursor and TUIO object?

	ID	Position	Orientation	Angle	Area
object	√	√	√		
cursor		√			

3. About Air Hockey Game Application

Question 5: How to eliminate warning C4819 in visual studio?

Answer: Project—>Properties —> C/C++ —> Advanced —> Disable specific warnings enter 4819

Question 6: How to eliminate the fatal error C1083

Answer: Project —>Properties —> C/C++ —>General —>Additional Include

Directories, enter corresponding head file name.

Note: In a VS project setting up the following issues is the basic knowledge.

- I Project — >Properties — > C/C++ — >General->Additional Include Directories, add corresponding include directories.**
- I Project — >Properties — > Linker — > General->Additional Library Directories, set corresponding lib directories.**
- I Project—>Properties —> Linker —> Input->Additional Dependencies, set corresponding library files.**